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LWP - 1050

May 15, 1972

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LANGLEY WORKING PAPER

EFFECTS OF SUSPENSION-LINE DAMPING ON LADT #3
AND SUPERSONIC BLDT PARACHUTE INFLATION DYNAMICS

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AUG 12 1974

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

EFFECTS OF SUSPENSION-LINE DAMPING ON LADT #3
AND SUPERSONIC BLDT PARACHUTE INFLATION DYNAMICS

By Lamont R. Poole

SUMMARY

A two-body computerized mathematical model is used to calculate planar dynamics of the LADT #3 and supersonic BLDT parachute inflations. Results indicate that the calculated loads and motions of the LADT #3 inflation are not affected appreciably by variation in the suspension-line damping coefficient. However, variation of the coefficient results insignificant changes in the calculated loads and strain rates of the supersonic BLDT inflation.

INTRODUCTION

Two parameters which are important in the design of parachute systems and the preflight analysis of missions employing such systems are the maximum drag force produced by the inflating canopy and the maximum force transmitted to the towing vehicle. Estimates of these parameters are normally based on previous flight experience or on approximate analytical solutions assuming a constant dynamic pressure. The analysis presented in reference 1 showed that suspension-line elasticity is a significant parameter in the prediction of opening loads under the assumption of constant dynamic pressure and considering the suspension system as an undamped linear massless spring.

A computer program (ref. 2) has been developed for numerical integration of the planar equations of motion of a general vehicle and parachute canopy. The equations are coupled by a two-component (bridle assembly and suspension lines) massless-spring mathematical model of suspension-system elasticity which

allows for nonlinear restoring forces and nonlinear damping. It is the purpose of this paper to present results obtained using this computer program which shows the influence of suspension-line damping on both the loads and motions of parachute inflation.

Specifically, this paper will apply the computer program to two inflations of the Viking parachute system. One inflation will be similar to that of the LADT #3 test extended to a probable time of full inflation; the other will be a simulation of the BLDT supersonic inflation. As actual damping characteristics of suspension-system material are presently not well defined, loads and motions for each case will be calculated for a wide range of suspension-line damping coefficients to show the influence thereof.

SYMBOLS

C_{DS}	canopy drag area, meters ²
F_V	instantaneous suspension-system force at vehicle attachment point, newtons
$F_{V,max}$	maximum calculated suspension-system force at vehicle attachment point for a particular damping coefficient, newtons
q	dynamic pressure, newtons/meter ²
$q_{\infty,bs}$	freestream dynamic pressure at bag strip (the beginning of inflation), newtons/meters ²
S_p	instantaneous canopy projected area, meters ²
$S_{p,fi}$	canopy projected area at full inflation, meters ²
t	time, sec
t_f	filling time, or time from bag strip to full inflation, sec

SYSTEM DESCRIPTION

A description of the LADT #3 decelerator system is given in reference 3. It is assumed that the mass of the LADT parachute system consists of the material mass plus enclosed and apparent air mass as described in that reference. A description of the BLDT Viking decelerator system is given in reference 4. For the BLDT system, it is considered that the mass of the added air is negligible due to the high altitude of the supersonic flight test.

Suspension-line and bridle-leg material force elongation data, as obtained by the Langley Research Center are presented in reference 3. For the purpose of this analysis, the bridle-leg material is assumed to have zero damping and each leg is considered to have four layers of material for computation of force-elongation characteristics for the total bridle assembly.

SIMULATION AND RESULTS

Program Input

For each of the inflations under study, vehicle and decelerator physical properties are used as program inputs. Inflation is assumed to begin under zero-load conditions at bag strip. Initial conditions at bag strip for each inflation were chosen so as to closely approximate the actual (or expected) flight conditions. For LADT #3, initial conditions are as follows: altitude, 13.4 kilometers; Mach number, 0.33; flight-path angle, -65.7 degrees. For the BLDT supersonic cases, initial conditions are as follows: altitude, 45 kilometers; Mach number, 2.16; flight-path angle, 16.0 degrees.

The opening time, or time from bag strip to full inflation, for LADT #3 has been selected, based on extension of the flight test data, as 0.7 seconds.

For the supersonic BLDT, a lower-bound opening time of 0.185 seconds has been selected based on data from the Planetary Entry Parachute Program. By the same methods, typical histories of drag area and projected area ratio have been selected for each flight test. The histories are shown in figure 1 for LADT #3, and in figure 2 for the supersonic BLDT. The drag area histories are chosen so as to result in maximum canopy drag forces of about 150,000 newtons for LADT #3 and about 100,000 newtons for the supersonic BLDT.

To examine the influence of suspension-line damping on the dynamics of each inflation, a series of cases are run for which all inputs except the suspension-line damping coefficient are held constant.

Program Results

The results of this study are not intended to be precise duplications (or predictions) of flight test data. The results are intended to show the basic differences between the inflation dynamics of LADT #3 and the BLDT supersonic cases and the extent to which the dynamics are affected by suspension-line damping. Therefore, the calculated data are presented in a normalized manner.

Normalized calculated histories of vehicle and canopy dynamic pressure for LADT #3, under the assumption of a 50 newton-second per line damping coefficient, are presented in figure 3. The canopy dynamic pressure is less than freestream dynamic pressure throughout most of the inflation process. Similar results were obtained when the suspension-line damping coefficient was varied from 0 to 200 newton-seconds per line. The fluctuation in canopy dynamic pressure is due to the inclusion of added mass terms in the equations of motion.

Normalized calculated histories of vehicle and canopy dynamic pressure for the BLDT supersonic case are presented in figure 4, again assuming a damping coefficient of 50 newton-seconds per line. Again, the canopy dynamic pressure is less than both the initial and instantaneous freestream dynamic pressure throughout the inflation range. Similar results were obtained when the damping coefficient was varied.

In figure 5 are shown the ratios of the maximum vehicle load to maximum canopy drag force for both LADT #3 and the BLDT supersonic case. These are presented as functions of the assumed suspension-line damping coefficient. For LADT #3, the load ratio is not significantly affected by the damping coefficient; it increases from a value of about 1.055 for a damping coefficient of zero to a value of 1.067 for a damping coefficient of 200 newton-seconds per line. However, for the BLDT supersonic case, the load ratio is strongly affected by the damping coefficient. From a maximum of 1.142 for a damping coefficient of zero, the load ratio decreases to 0.829 for a damping coefficient of 200 newton-seconds per line.

Another parameter which exemplifies the differences in the two inflations is the relationship between the rate at which the suspension lines are strained during inflation and the force which the lines must carry at these rates. Curves of normalized suspension-system force (force/maximum vehicle force) versus strain rate for damping coefficients of 0 and 200 newton-seconds per line for LADT #3 are presented in figure 6. It can be seen that maximum strain rates are low ($\approx 70\%/sec$) and these rates occur at times when the lines are experiencing only about 40 percent of the maximum load. It can also be seen that the general characteristics of the curve are not strongly affected by the damping coefficient.

Analogous curves for the BLDT supersonic case for damping coefficients of 0, 100, and 200 newton-seconds per line are presented in figure 7. In this case, maximum strain rates are high (250-300%/sec). The maximum-load/maximum-rate relationship is quite strongly affected by the damping coefficient. As an example, for a damping coefficient of 200 newton-seconds per line, the maximum rate and maximum load occur almost simultaneously.

CONCLUSIONS

A two-body computerized mathematical model of parachute inflation, which includes nonlinear suspension-system elastic properties, has been used to calculate the loads and motions for two inflations of the Viking parachute system: an inflation similar to that of the LADT #3; and a simulation of the supersonic BLDT inflation. A series of cases was run for each inflation, varying the suspension-line damping coefficient from 0 to 200 newton-seconds per line in order to determine the effects thereof. Based on the results of these calculations, the following conclusions are made:

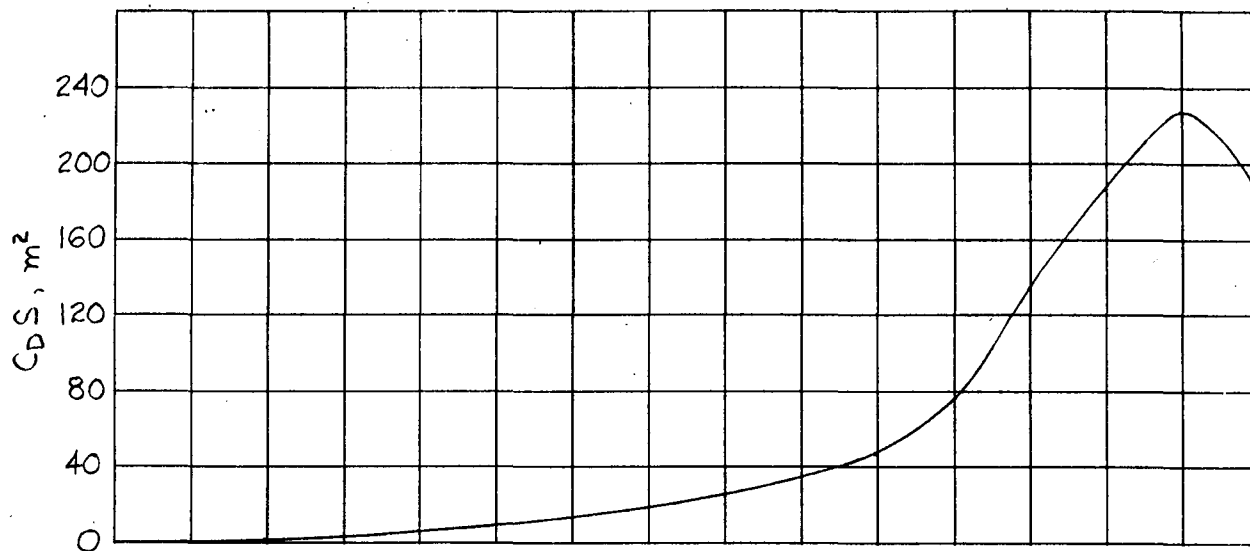
1. The dynamic pressure history of neither the LADT #3 nor the supersonic BLDT inflation was significantly affected by variations in the damping coefficient.
2. The ratio of the maximum vehicle load to the maximum canopy drag force, in the case of LADT #3, is not significantly affected by variations in the damping coefficient. The ratio varies from 1.055 for a damping coefficient of zero to 1.067 for a damping coefficient of 200 newton-seconds per line.
3. For the BLDT supersonic inflation, the load ratio is quite strongly affected by the damping coefficient. The ratio decreases from 1.142, for a damping coefficient of zero, to 0.829 for a damping coefficient of 200 newton-seconds per line.

4. For LADT #3, maximum suspension-line strain rates are on the order of 70 percent per second, which occur at times when the lines are experiencing about 40 percent of the maximum force for that particular case. The general characteristics of the force/strain-rate curve are not significantly affected by variation in the damping coefficient.

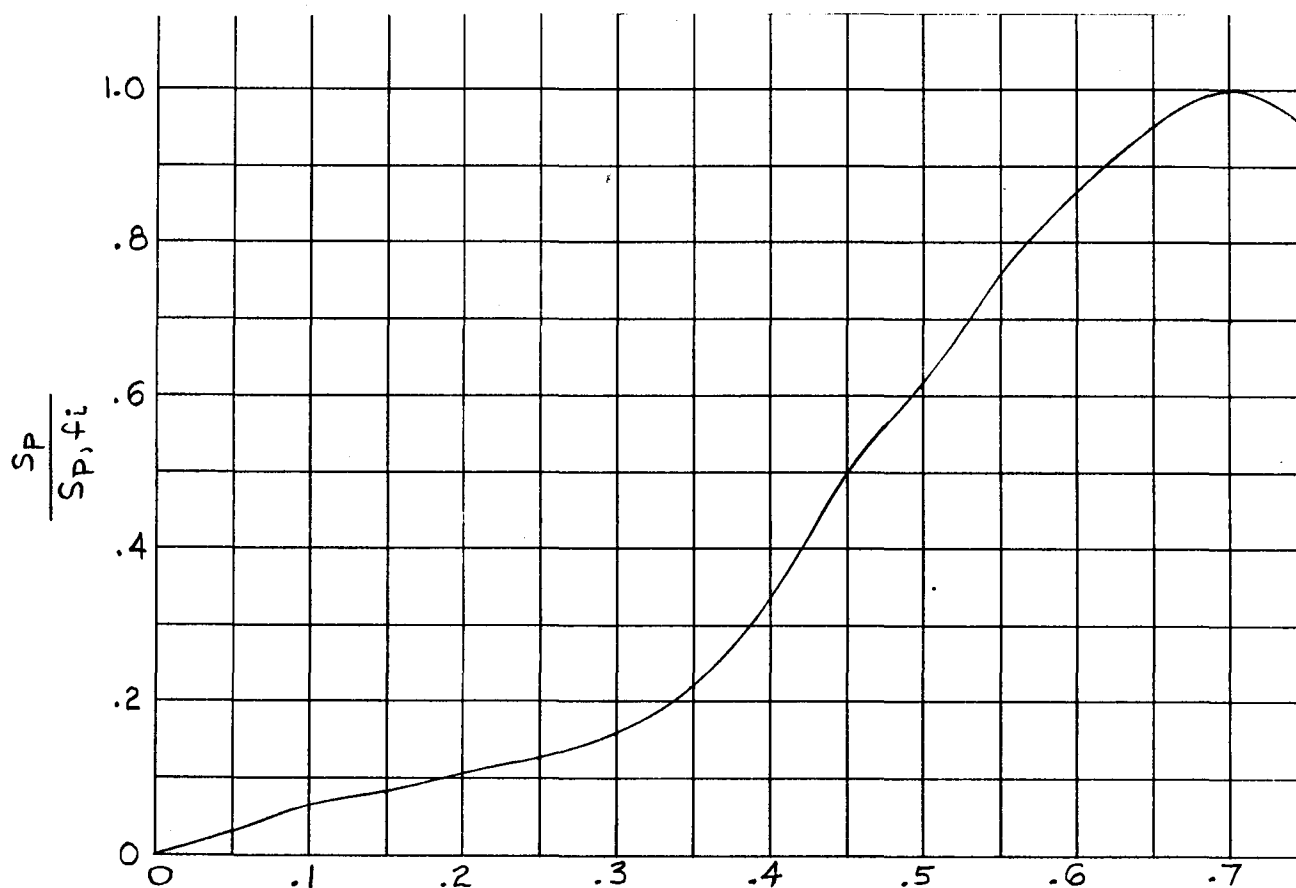
5. For the BLDT supersonic inflation, maximum suspension-line strain rates vary from 250 to 300 percent per second. The force/strain-rate curve is strongly affected by the damping coefficient. As an example, for a damping coefficient of 200 newton-seconds per line, the maximum load and the maximum strain rate occur almost simultaneously.

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2. Poole, Lamont R.: Computer Program for Calculating Planar Inflation Dynamics of Parachutes Having Nonlinear Suspension-System Elastic Properties. Prospective NASA TM.
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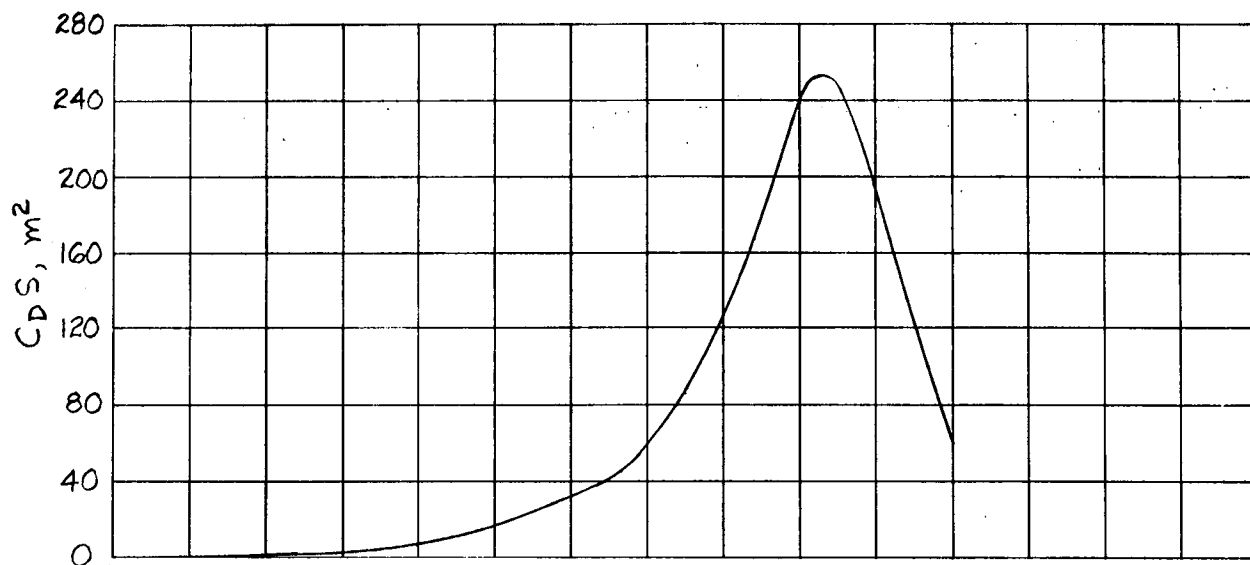


(a) Drag area

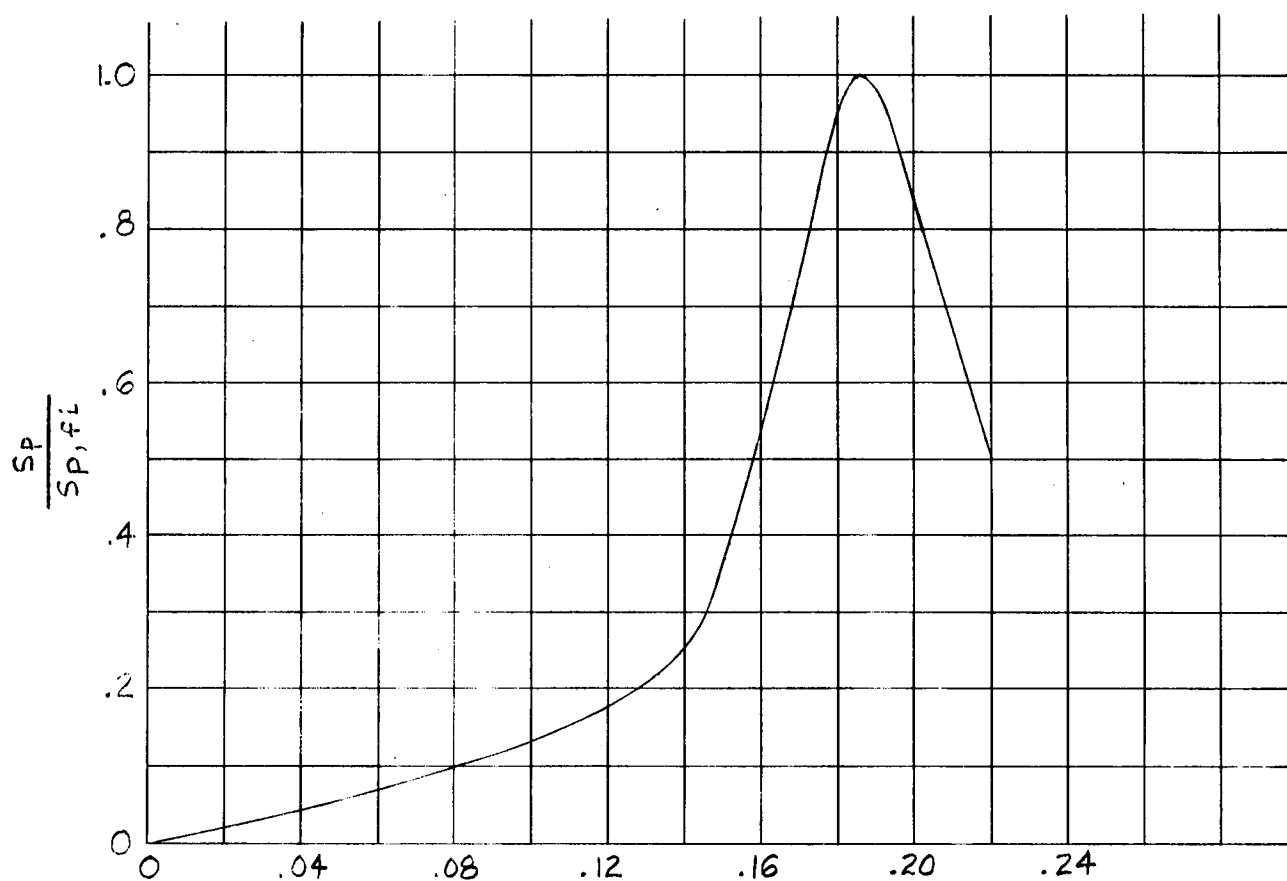


Time from bag strip, sec
(b) Projected area ratio

Figure 1.- Input histories of drag area and projected area ratio for LADT#3 inflation.



(a) Drag area



(b) Projected area ratio

Figure 2.- Input histories of drag area and projected area ratio for supersonic BLDT inflation.

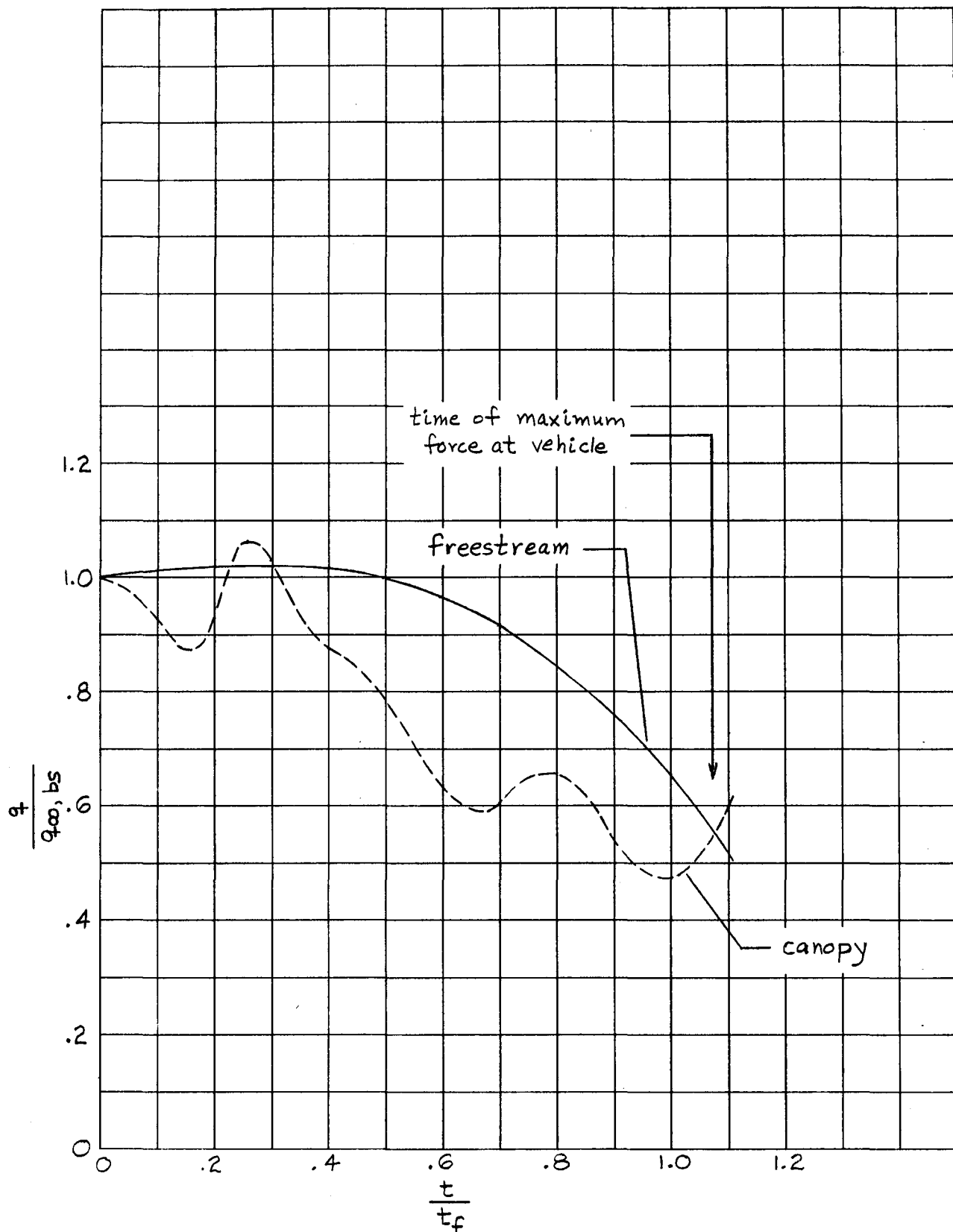


Figure 3.- Normalized histories of freestream and canopy dynamic pressure for LADT #3 inflation; damping coeff.= 50 N-sec/line.

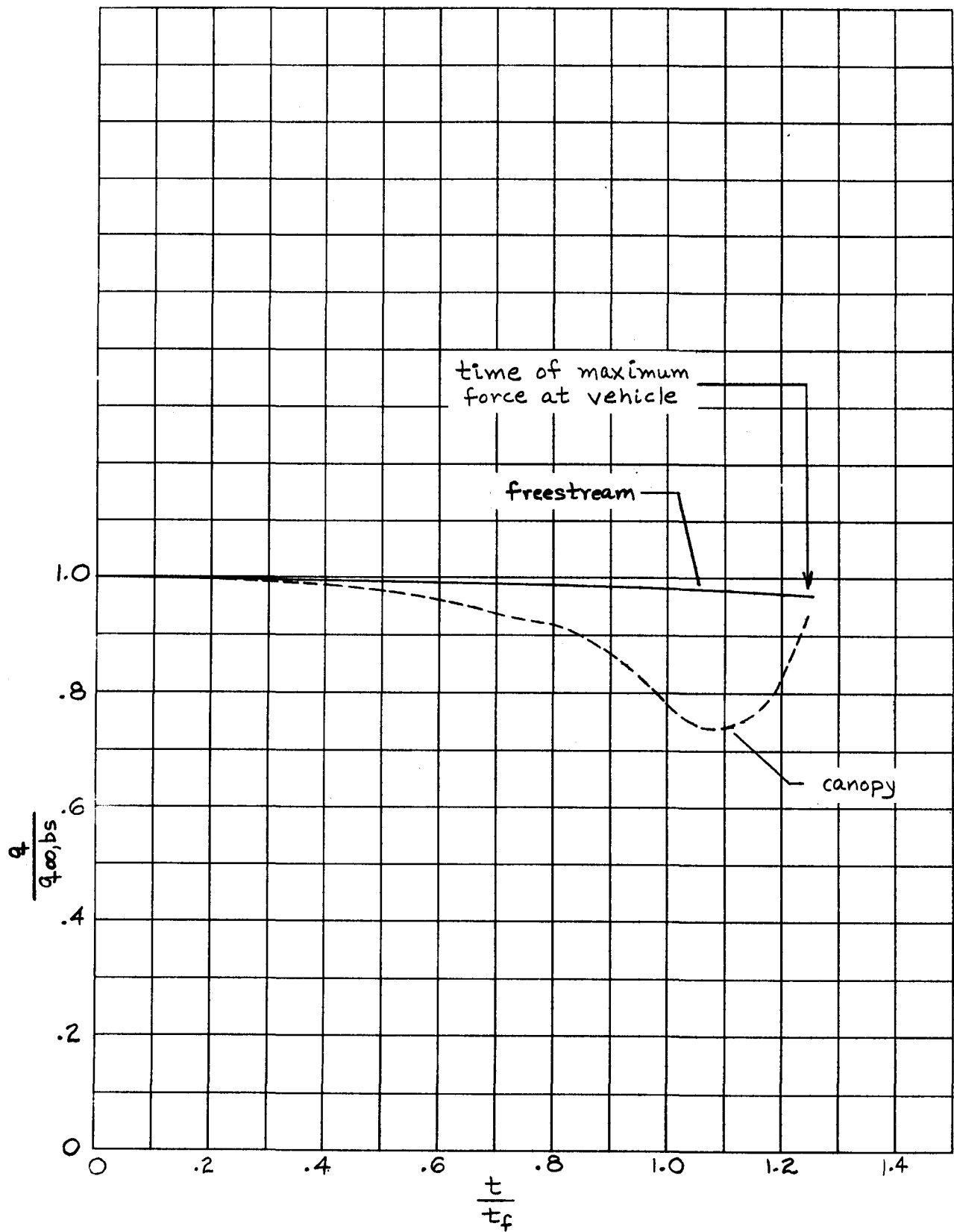


Figure 4.- Normalized freestream and canopy dynamic pressure histories for the supersonic BLDT inflation; damping coeff. = 50 N-sec/line.

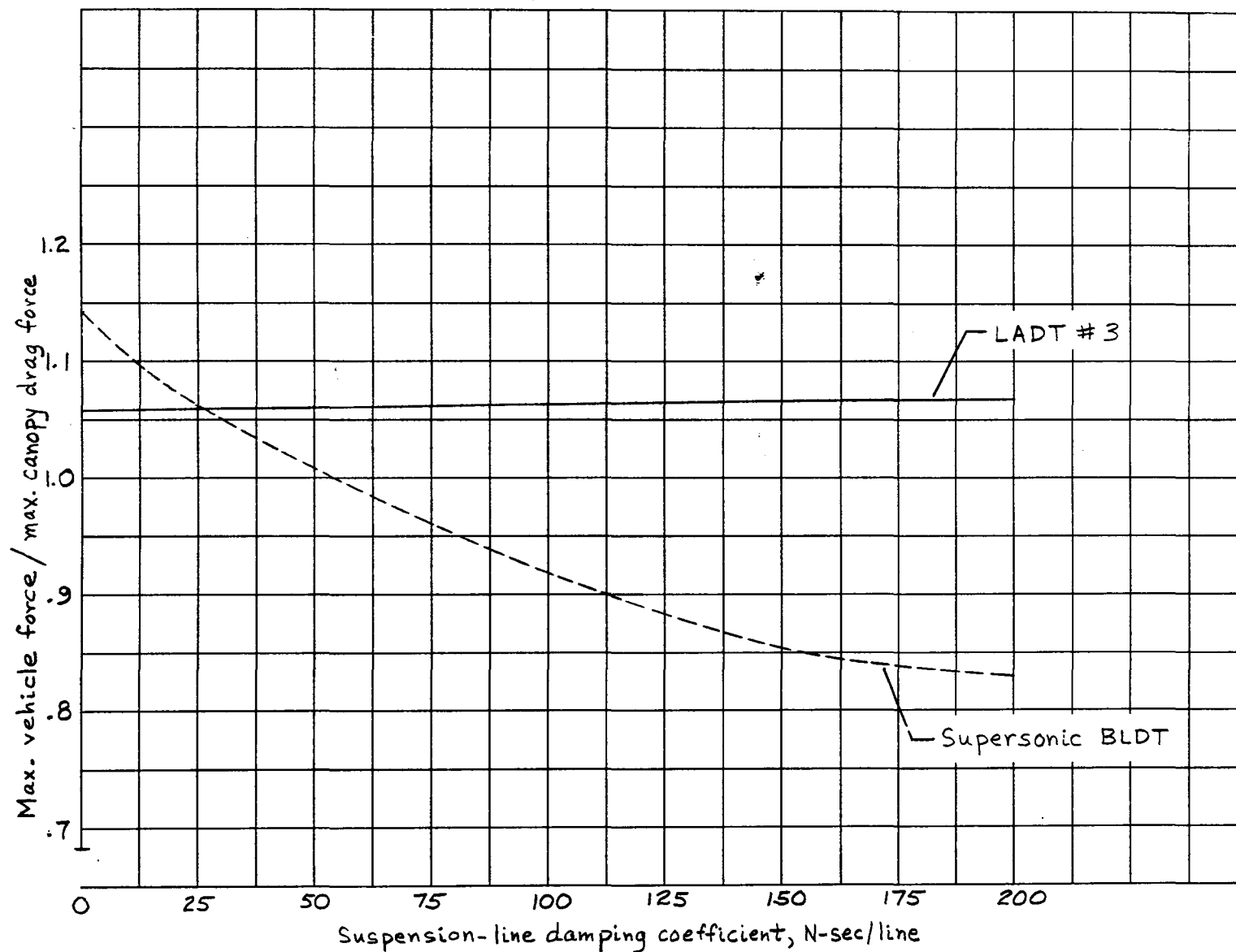


Figure 5.— Ratio of maximum vehicle force to maximum canopy drag force for LADT#3 and supersonic BLDT inflations as a function of assumed damping coefficient.

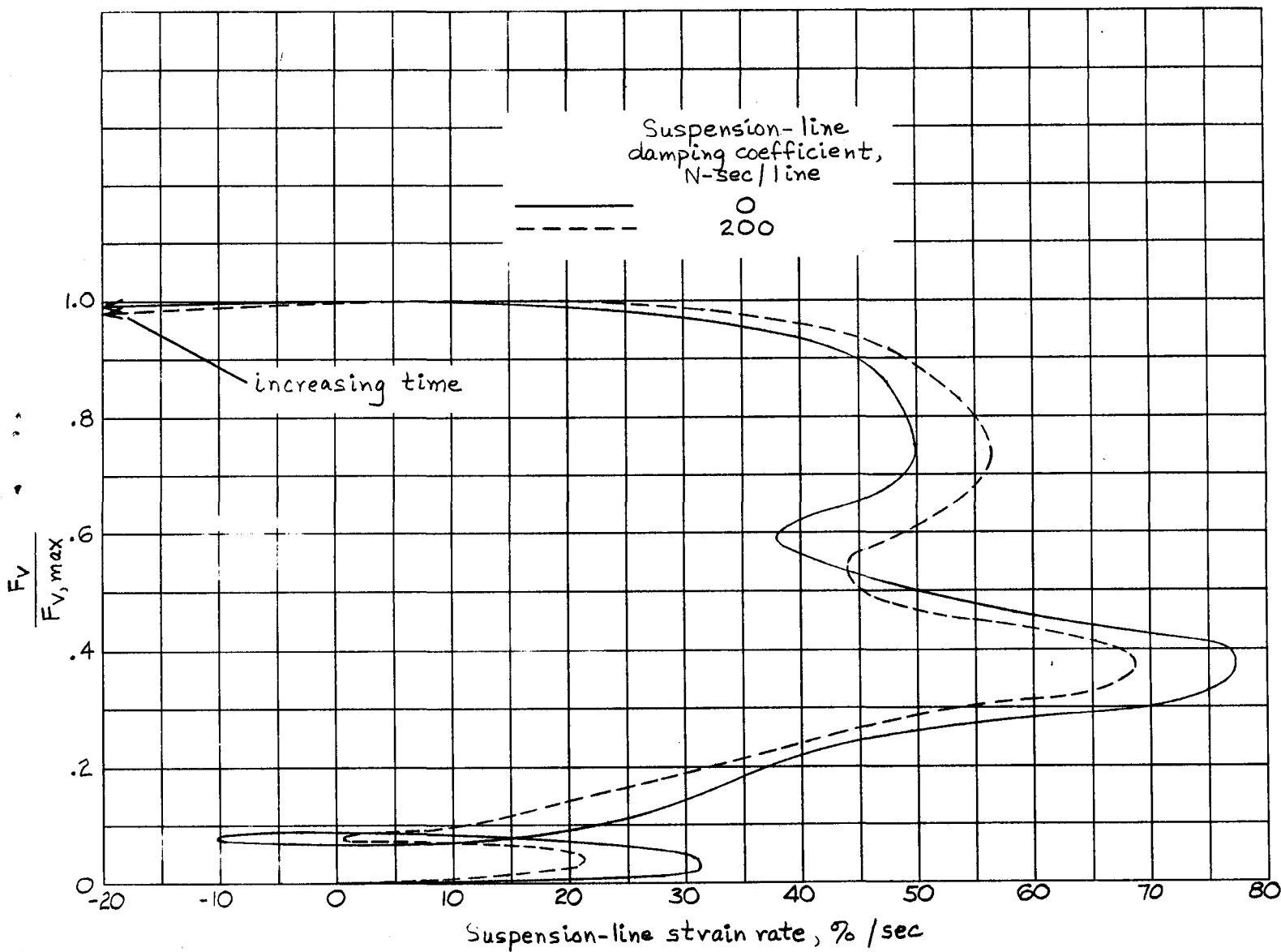


Figure 6.- Ratio of vehicle force to maximum vehicle force for LADT#3 inflation, as a function of suspension-line strain rate, for two damping coefficients.

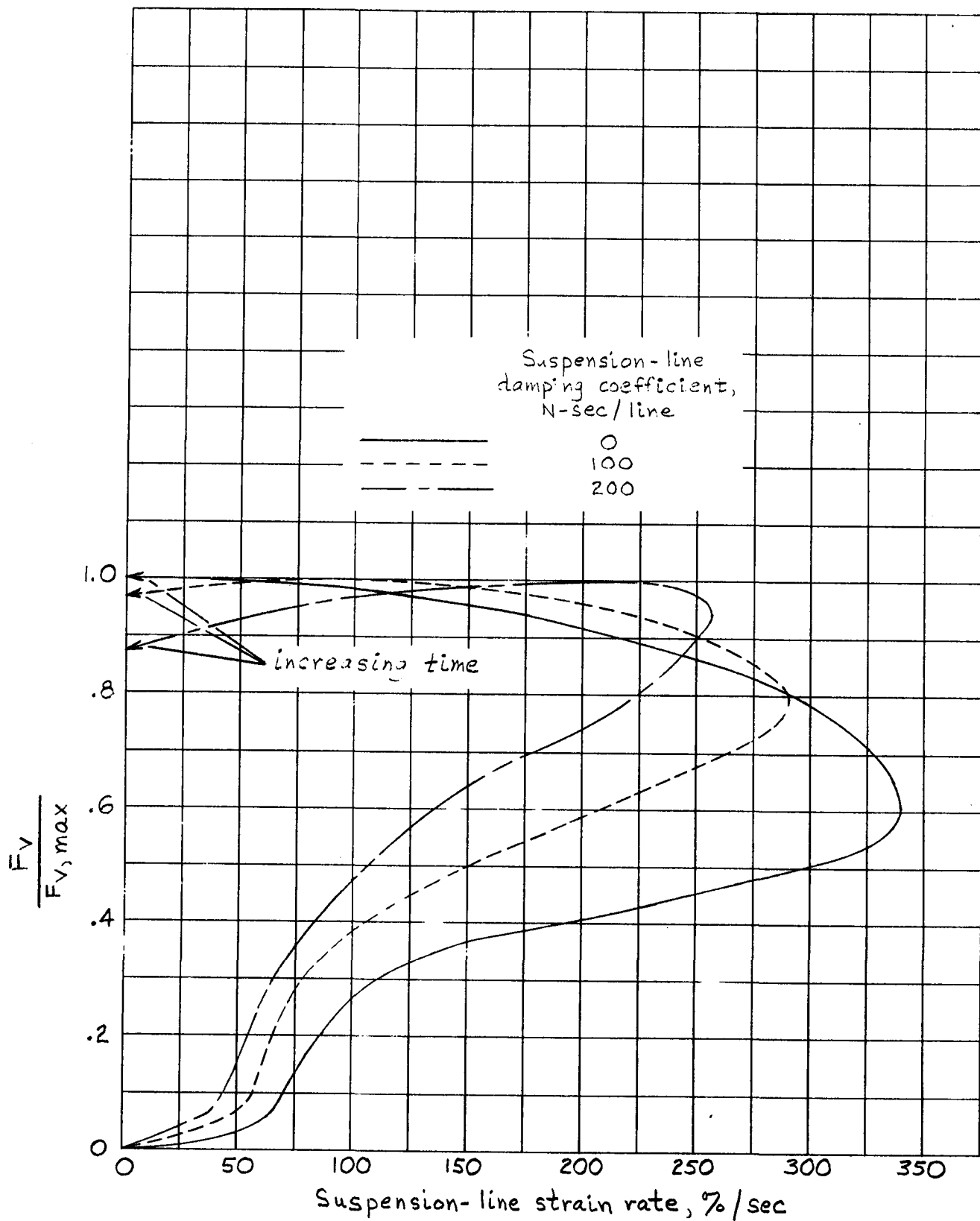


Figure 7.— Ratio of vehicle force to maximum vehicle force for the supersonic BLDT, as a function of suspension-line strain rate, for several damping coefficients.